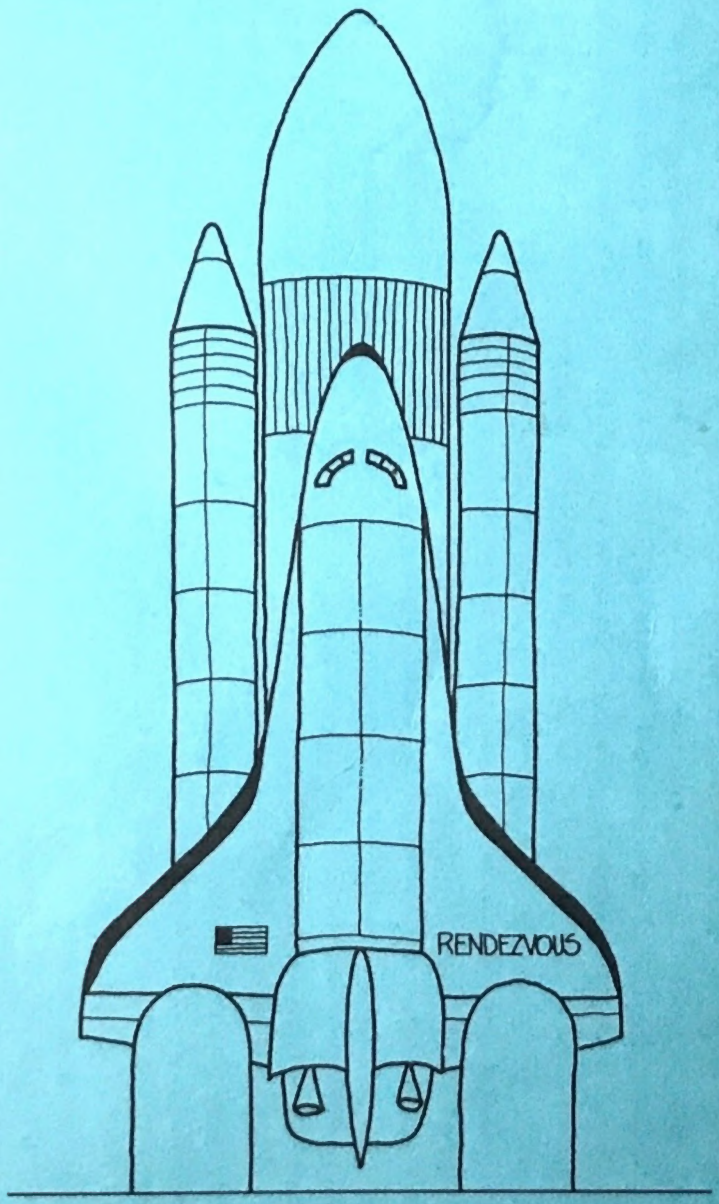
RENDEZVOUS™



Operations Manual

by Wesley Huntress, Ph.D.

EDU-WARE®

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I. SELECTING YOUR MISSION PROFILE

STARTING

When you first boot your RENDEZVOUS diskette, a menu will appear. From this you may choose to start at any of the system's four phases.

1. **EARTH LIFTOFF** — Start at the launch pad. Select this option to experience the entire simulation from beginning to end.

2. **ORBITAL RENDEZVOUS** — Start in earth orbit. Choose an initial circular orbit and position relative to the space station.

3. **APPROACH** — Start in the same orbit as the space station. Choose your distance and velocity relative to the space station.

4. **ALIGNMENT AND DOCKING** — Start in the vicinity of the space station. Choose a position relative to the station and maneuver your craft into the docking port.

Choose any phase and RENDEZVOUS will prompt you for the data required to proceed. The questions are self-explanitory. To familiarize yourself with the tactical skills and objectives in each phase, we suggest you use the following initial positions:

1. **LIFTOFF** — no data entry required.

2. **ORBIT** — orbital radius 1.3; relative anble −18 degrees. As soon as orbital motion proceeds, set up an orbital maneuver with a thrust angle of Ø degrees and a delta-V of about 600 meters/second (m/s). Project the trial orbit forward to see what happens.

3. **APPROACH** — distance 4 kilometers; velocity Ø meters/second; zero off-axis distance and velocity. On approach, accelerate towards the station at 20 meters/second and watch.

4. **ALIGNMENT AND DOCKING** — axial distance 300 meters; horizontal and vertical distance Ø meters; bank "easy." When you arrive at the station, accelerate forward to 2 meters/second and watch.

You will be heavily penalized for using these initial conditions, but they will serve to introduce you to the simulation.

POSITION YOUR FILES

A. The Phase Menus

When you enter phases 2 (Orbital Rendezvous), 3 (Approach), and 4 (Alignment and Docking), a Phase Menu appears. This menu presents two options: you may set up your flight parameters for the phase, or you may retrieve and load a position which you have previously saved under a file name. Simply respond to the menu's prompts, and RENDEZVOUS will do the rest.

If you decide to set up flight parameters, you may afterwards save them on disk to use again. You can save up to 10 positions each for phases 2, 3, and 4. Assign any name with up to 20 characters to each position; the same names may be used for positions filed in different phases.

If you already have accumulated 10 file names in a given phase and now wish to save a new position, the system will ask which of the 10 existing positions you wish to replace.

When you wish to retrieve a saved position, a list of all files previously saved in that phase will appear. Select the number next to the file name you want. If you decide not to retrieve any of the positions displayed, press the (Ø) key and the system will return you to your previous position.

B. Options Menu

You may save your position or load a new position file from the Options Menu in phases 2, 3, and 4. Access the menu in phase 2 while proceeding on orbit by pressing any key. Access the menu in phases 3 and 4 by pressing the (ESC) key at any time.

> **NOTE:** The second portion of this manual gives an operational summary of each of RENDEZVOUS' four phases. This summary is intended to acquaint you with the object of each phase, the methods for accomplishing it, and the operation of the computer towards that objective. The third section of the manual gives a detailed and more physical description of events in each phase. The fourth section provides a tutorial and how to maneuver your spacecraft in the Approach and Docking phases using the keyboard or a joystick.

II. AN OPERATIONAL SUMMARY

Phase One: EARTH LIFTOFF

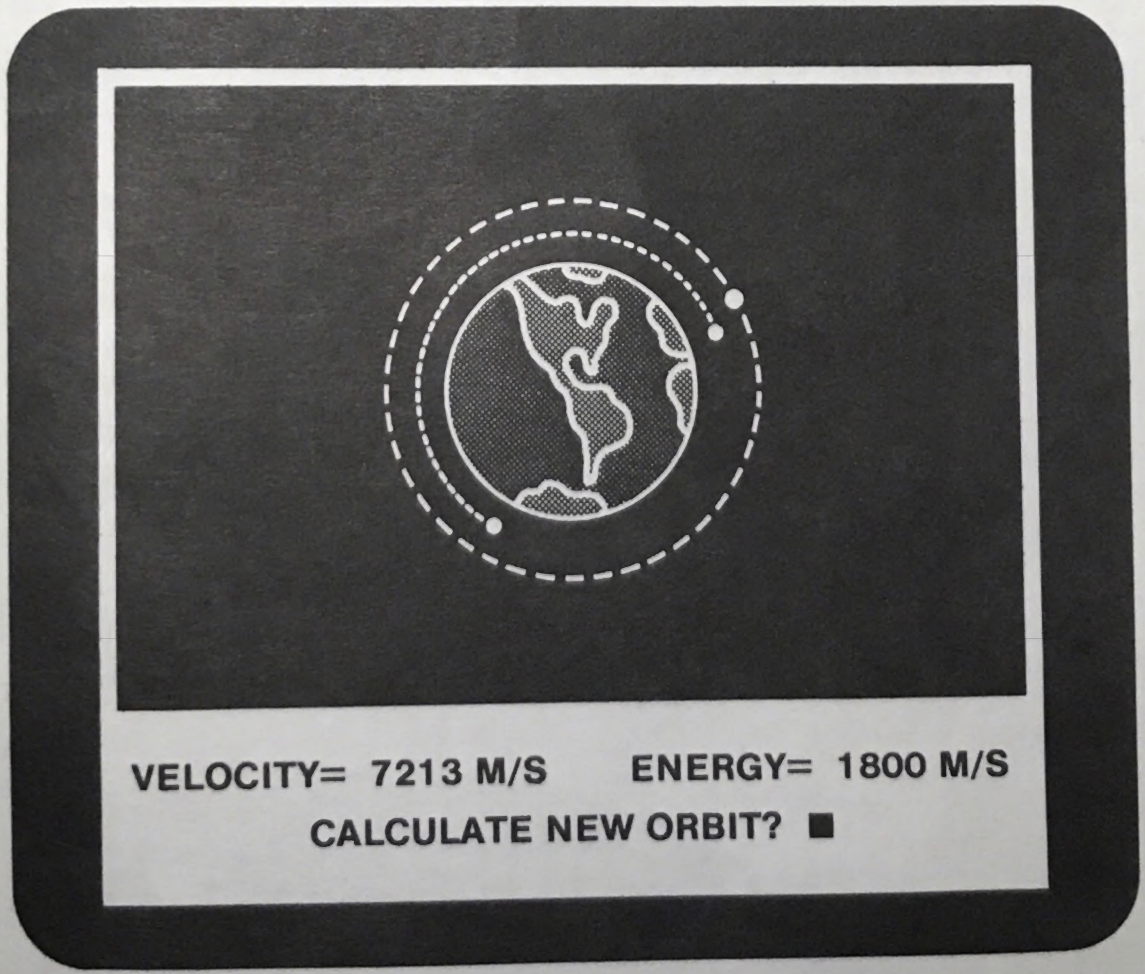
OBJECT: Launch your spacecraft and achieve orbit. Minimum altitude is 191 kilometers (ALT: 191 KM) and minimum horizontal velocity is 7,800 meters a second (VELX: 7800 M/S). A perfect orbit requires near zero vertical velocity (VELY).

OPERATION: (Return) key: ignites booster
toggles shuttle engine
Left arrow key (←): tips rocket down
Right arrow key (→):tips rocket up

Phase Two: ORBITAL RENDEZVOUS

OBJECT: Match orbits in the immediate vicinity of the space station. The space station holds a circular orbit 1.50 earth radii from the surface.

METHOD: Make orbit changes to rendezvous with the station. You move faster than the station in orbits closer to the earth, and slower in orbits farther from the earth. Once near the station, adjust your orbit to one which crosses the orbit of the station. When you reach the point where your transfer orbit crosses the orbit of the space station, make your orbit circular. The hard part is insuring that you are in the immediate vicinity of the station when you match orbits with it.



OPERATION:

STEP #1: Interrupt orbital motion. Any key will stop orbital motion and show a menu:

(1) key: choose maneuver position
(2) key: Options Menu
(3) key: return to orbital cruise

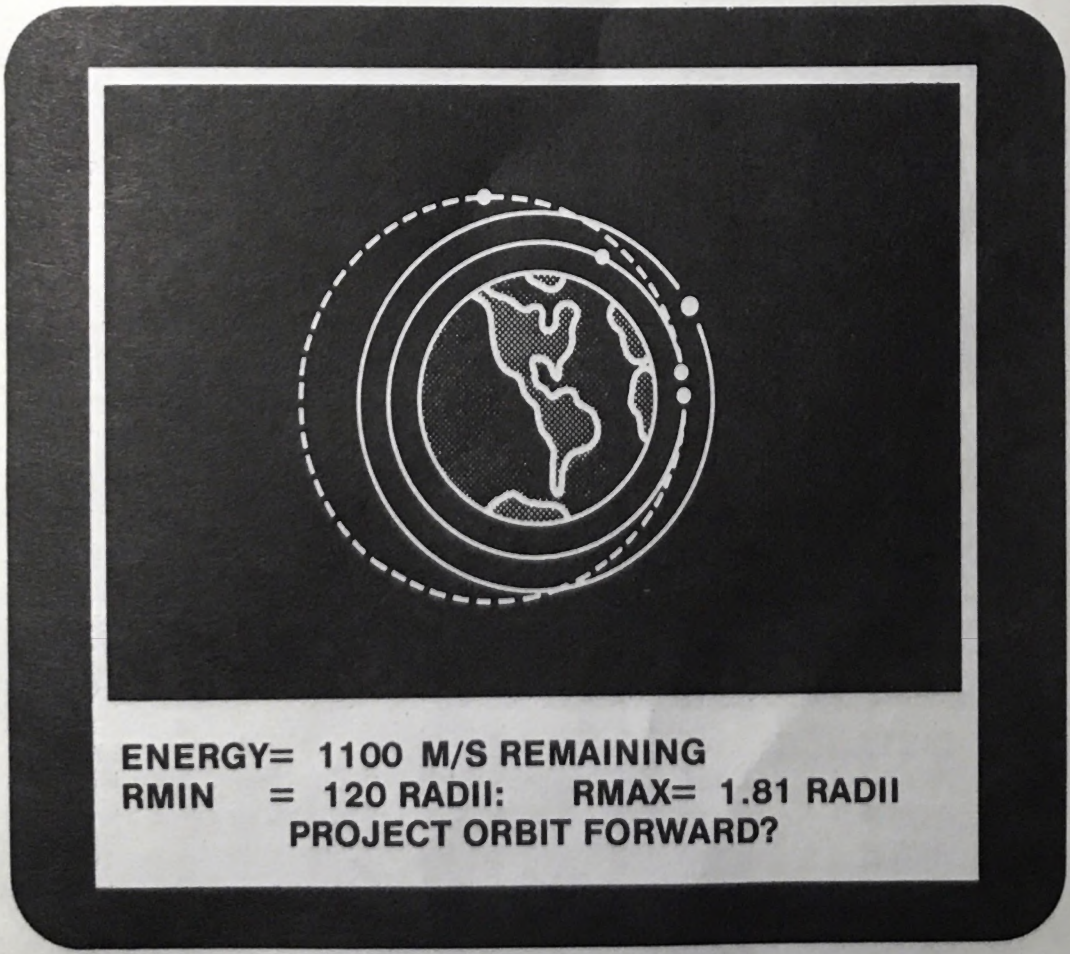
STEP #2: Press (1) to choose maneuver position. Use the arrow keys to project the orbit forward in time. Press the return key when you have projected the orbit to where you'd like to begin a new trial orbit.

Right arrow key (→): project forward along orbit
Left arrow (←) key: project backward along orbit
(RETURN) key: manuever position selected

STEP #3: Press (RETURN) to set up a new trial orbit. If you want a circular orbit, then answer (Y) to the "Auto-circularize?" question. If not, then answer (N) and you will be asked to enter the thrust angle and velocity:

Thrust angle: engine burn direction.
Ø DEG is forward to speed up.
180 DEG is backward to slow down.
Delta-V: velocity change in M/S.

STEP #4: Decide if the trial orbit is satisfactory. The trial orbit parameters will be calculated, and if you like them the trial orbit will be plotted. Project the spacecraft along the new trial orbit if you wish to see it the new orbit will intercept with the space station.



If at any time during the projection process the spacecraft is close enough to the station for rendezvous, a large cross will be plotted over that point. Remember that your orbit must reach a 1.5 radius to do this.

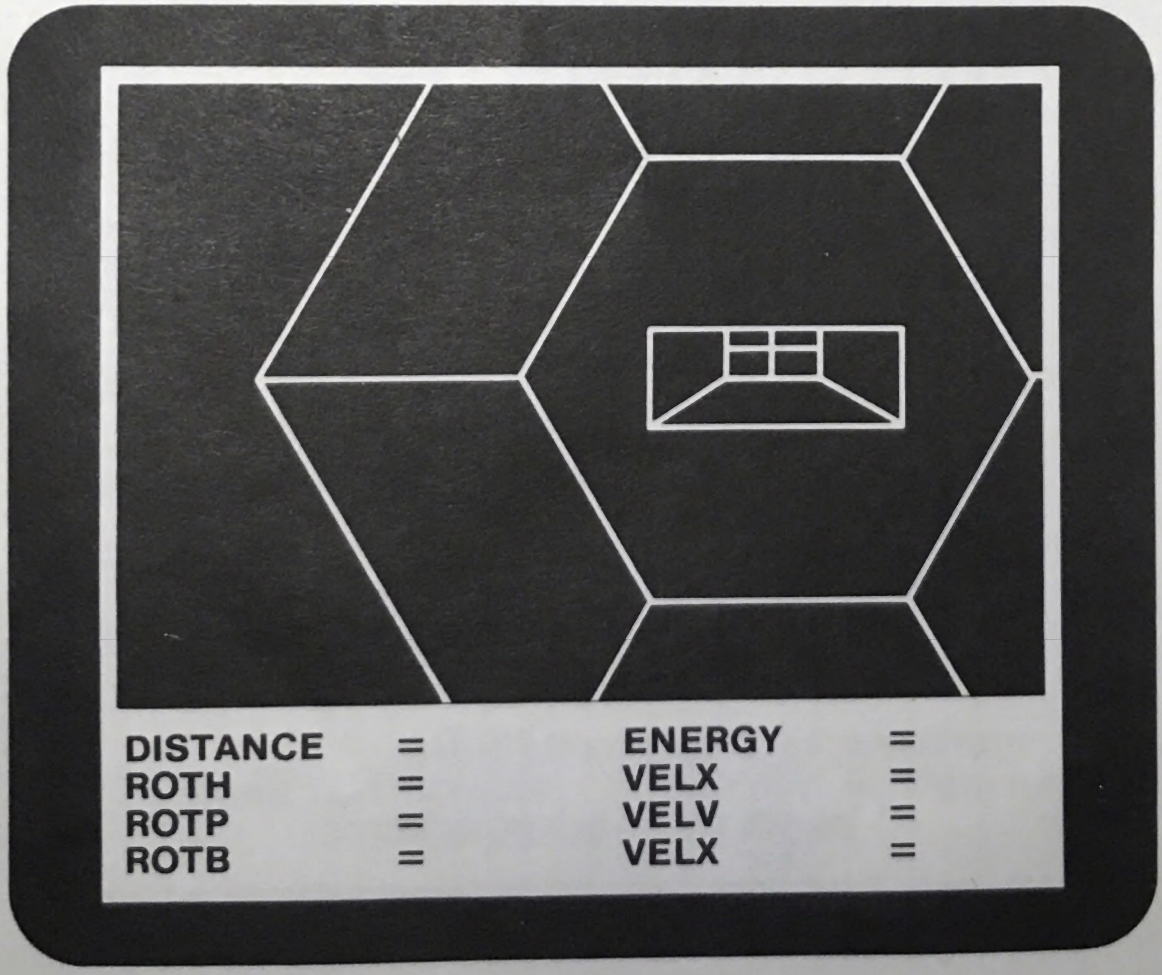
Accept or reject the trial orbit. If accepted, the orbit change maneuver will be automatically done at the chosen point along the orbit.

STEP #5: Once you have entered an orbit which has a rendezvous crossing, set up a final orbit change maneuver to circularize the orbit just at the rendezvous point. Do this BEFORE you reach the rendezvous point. If this maneuver is successful, then you will automatically transition to the Approach phase.

THE OPTIONS MENU

(Also available in APPROACH and ALIGNMENT AND DOCKING phases)

The Options Menu is accessed by using the (2) key in the Orbit Phase and the (ESC) key in Approach and Alignment and Docking. From the menu you may save your present position to disk, load a new position file, go back to your original position, return to your present position, return to the Rendezvous Menu program or quit.

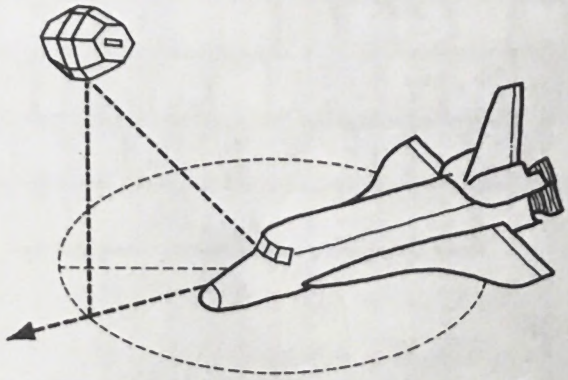


Phases Three and Four:
APPROACH and ALIGNMENT AND DOCKING

OBJECTIVE: Approach within 2 km. in all directions of the space station to enter the Docking phase. Once in the Docking phase you will 1) maneuver toward the docking port, then 2) align with and enter the docking hangar.

METHOD: Use either the keyboard or a joystick to maneuver the spacecraft. In the Approach phase you have control only over spacecraft directional motion. In the Docking phase you also control spacecraft rotation.

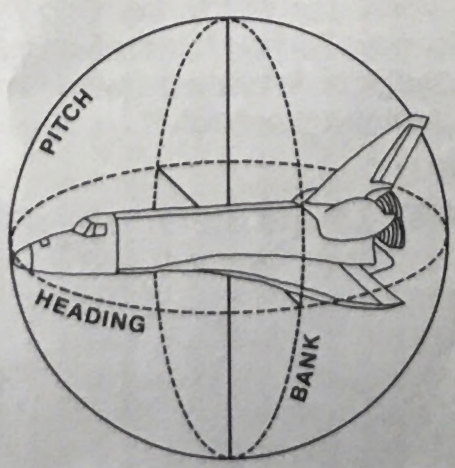
OPERATION: Operations in both the Approach and Alignment and Docking phases are very similar and are therefore covered here in the same section.



USING THE KEYBOARD

Movement

(M) key: move down (decreasing Y)
(I) key: move up (increasing Y)
(J) key: move left (decreasing X)
(K) key: move right (increasing X)
(L) key: move back (decreasing Z)
(;) key: move forward (increasing Z)

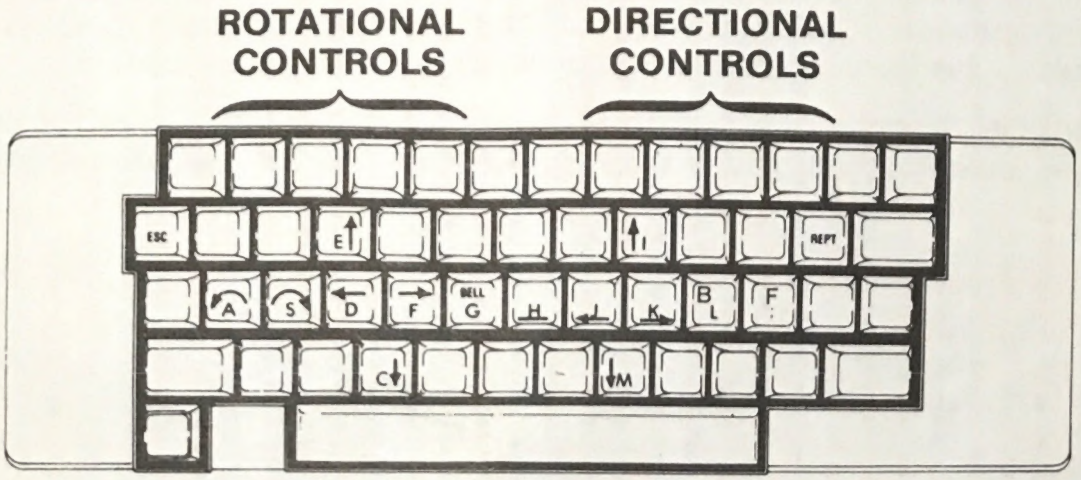


Rotation

(C) key: rotate down (decreasing pitch)
(E) key: rotate up (increasing pitch)
(D) key: rotate left (decreasing heading)
(F) key: rotate right (increasing heading)
(A) key: roll left (decreasing bank)
(S) key: roll right (increasing bank)

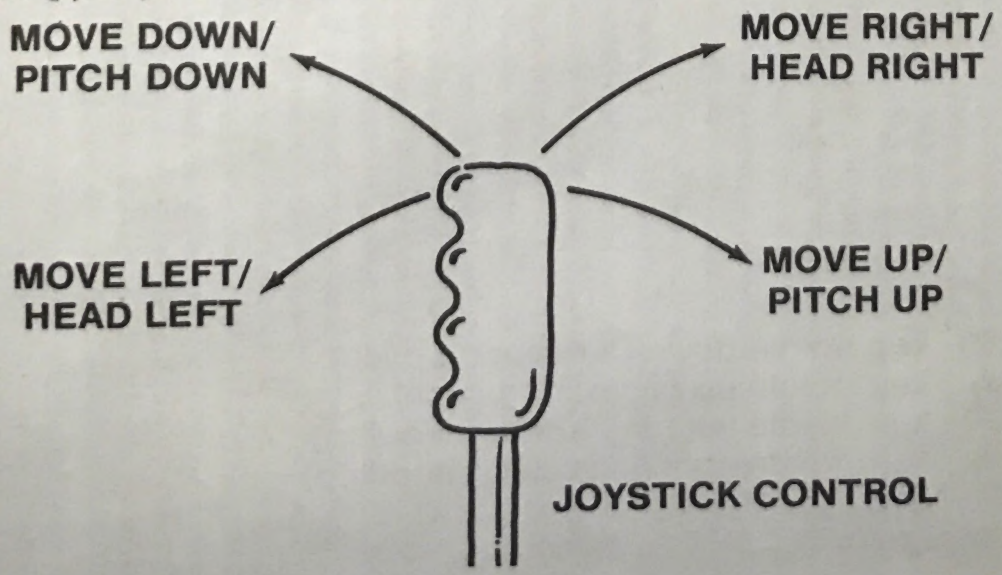
KEYS USED IN BOTH JOYSTICK AND KEYBOARD MODES

(G) key: toggle viewfinder (docking only)
(H) key: toggle approach radar (docking only)
(RETURN) key: kill residual motion (docking corridor)
(Space) bar: kill all rotational motion
(ESC) key: interrupt to Options Menu



USING A JOYSTICK

Joystick UP: move down (decreasing Y), or rotate down (decreasing pitch)
Joystick DOWN: move up (increasing Y), or rotate up (increasing pitch)
Joystick LEFT: move left (decreasing X), or rotate left (decreasing heading)
Joystick RIGHT: move right (increasing X), or rotate right (increasing heading)
Switch #1: move back (decreasing Z), or roll left (bank left)
Switch #2: move forward (increasing Z), or roll right (bank right)
Switch #3 or (/) key: toggle Joystick between movement control and rotation control



SCORING

Three criteria are used to evaluate your skill: time, energy and piloting. The less time you take, the less energy you use, and the more piloting skill you demonstrate result in a higher score. The elapsed time and energy consumed are reported after docking, or as a status check when the Options Menu is accessed. You evaluate your own score on elapsed time and energy consumed. The computer will score you on piloting skill in the Approach and Docking phases. The scores reported are from the lowest to highest:

ZERO!
SWAB
ENSIGN
LIEUTENANT
COMMANDER
CAPTAIN
ADMIRAL
FLEET ADMIRAL

WARNING

Do not hit the (RESET) key. The disk will re-boot every time.

Do not hit (CTRL)-(C). You can get away with this sometimes, but other times the system will hang or break to an unresponsive Applesoft prompt, sometimes with an error message.

III. A DESCRIPTION

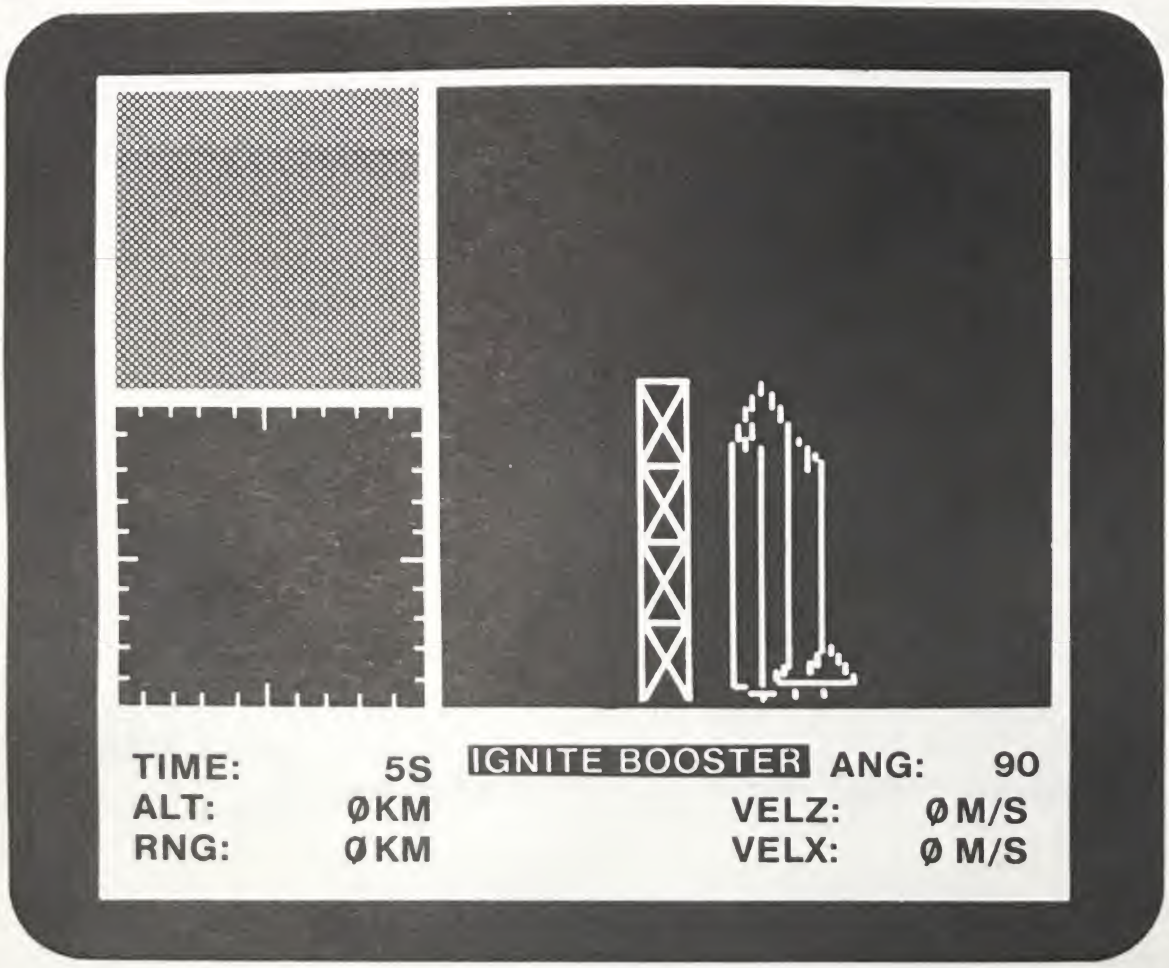
Phase One: LIFTOFF

You are about to set out on a journey into space, flying your space shuttle craft to rendezvous with an earth orbiting space station. Your vehicle is an advanced version of the original NASA shuttle, upgraded and modified for an invigorated space program. The heritage of Mercury, Gemini, and Apollo is behind you.

You start at an earth launch site with an external view of your advanced space shuttle multi-stage rocket standing ready for liftoff. Pressing the (RETURN) key will ignite the booster rockets. You can pitch the rocket toward a horizontal heading after it has cleared the tower by using the left arrow (←) key. The right arrow (→) key will pitch the rocket back up toward a vertical heading. The instrument panel at the bottom of the screen gives you data on your position and velocity, while the the plot on the left of the screen shows your progress in graphic form.

Your goal is to reach a minimum orbital altitude (ALT) of 191 km. with a minimum horizontal velocity (VELX) of 7800 meters/second. The altitude requirement is somewhat arbitrary, but below this altitude the atmosphere remains sufficiently dense to drag a shuttle craft down after a few orbits. The horizontal velocity is necessary in order to overcome the force of gravity.

You can accomplish this easily given the capabilities of your spacecraft and a minimum of piloting skill. Remember, your ultimate success in docking with the space station hinges upon reaching an initial advantageous orbit with as much fuel remaining as possible.



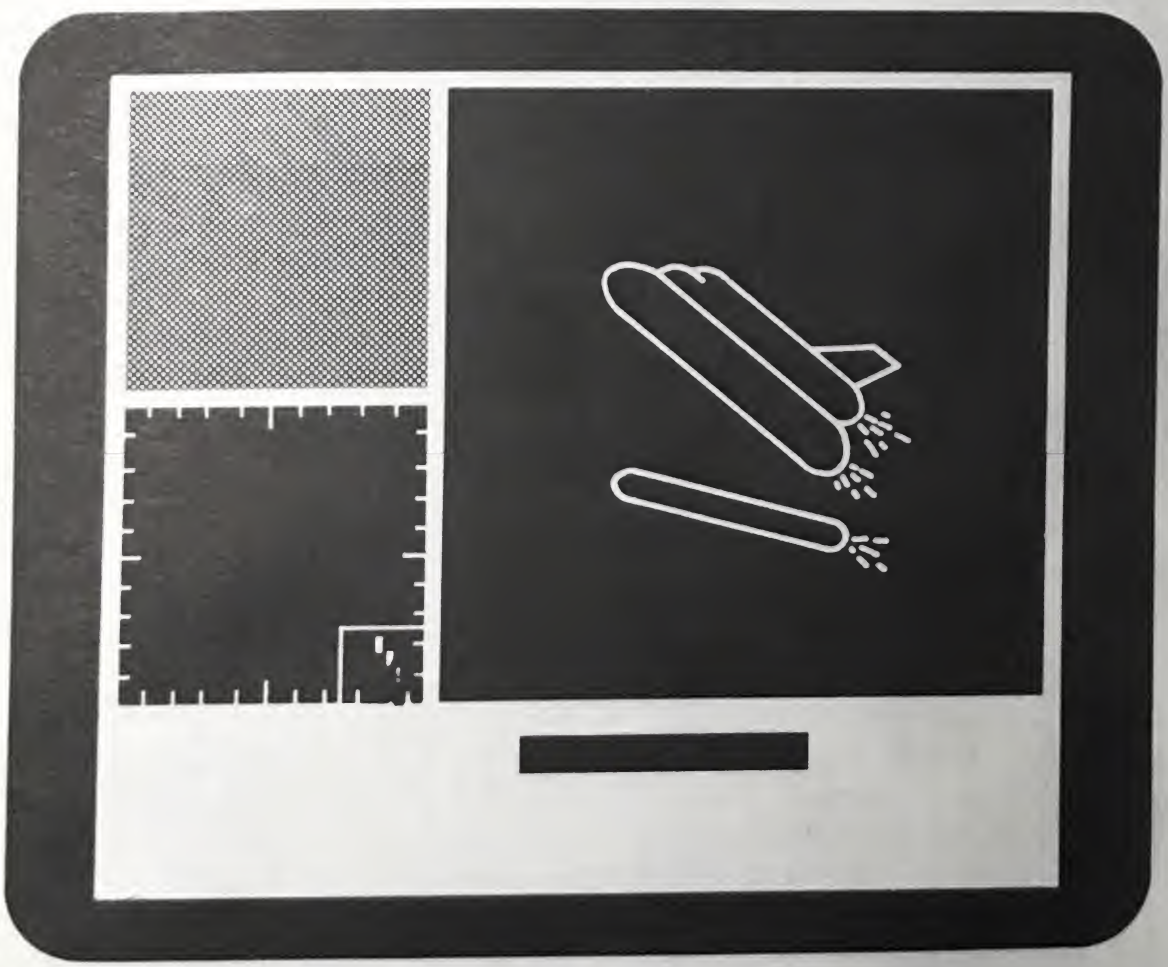
The original NASA shuttle (the model for your craft) holds solid-fueled boosters and a large expendable external tank to fuel the sustainer engines on the shuttle body. Orbital maneuvers use smaller engines in tail pods next to the sustainers. Your RENDEZVOUS shuttle craft is also boosted by two stages, but the burn times are shorter and the sustainer engines are a part of the external tank. The booster burns for 90 seconds and gets you through the dense parts of the atmosphere with sufficient altitude and velocity for the sustainer to carry you on to orbit. The sustainer burns for 200 seconds and should easily carry you to orbital altitudes and speeds.

The booster and sustainer burn and stage automatically. The only control you have during this phase of the flight is over the attitude of the space craft using the right (→) and left (←) arrow keys. If you have failed to reach sufficient altitude or velocity after the sustainer stages, you can ignite the shuttle engine with the (RETURN) key. Turn the shuttle engine off by pressing the (RETURN) key a second time. Economize your shuttle's energy, however, as you will need it for orbital maneuvers, and Approach and Docking.

The booster and sustainer can pitch the craft only during engine burn. The shuttle has an altitude control system separate from the main engine which can be ignited at any time.

A perfect initial orbit is rarely achieved—even the NASA space shuttle uses a trim burn with the orbital engines to move into a circular orbit. You will most always suffer some residual vertical velocity which will carry you into an elliptical partial orbit. This is quite acceptable, since you can trim your orbit in the next phase, and take advantage of the altitude to reach the space station orbiting at 1.50 earth radii (3185 km. above the earth). To achieve perfect orbit, your vertical velocity should be near zero at engine cut-off.

Remember in this phase your trajectory is ballistic . This means that the vertical velocity is determined by three factors: the force of gravity, the vertical thrust applied to counteract gravity, and the horizontal velocity. The horizontal velocity, which changes only with applied horizontal acceleration, is critical because it provides centrifugal force to overcome gravity. No vertical thrust is required in orbit since the horizontal velocity is sufficient to balance gravity.



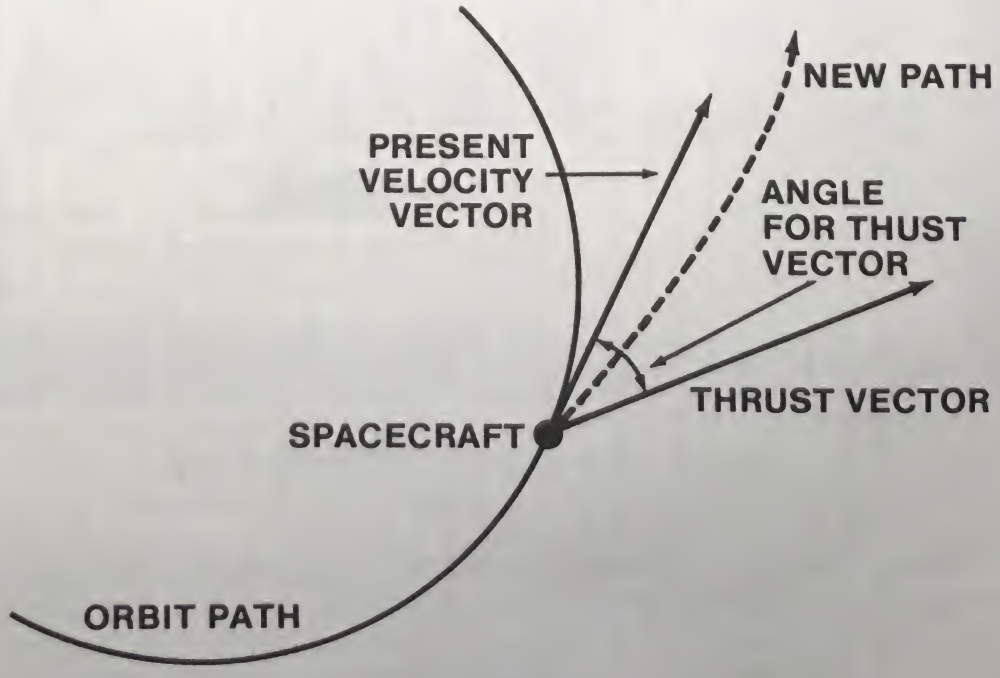
Phase Two: ORBITAL RENDEZVOUS

Once you have achieved orbital velocity and altitude, RENDEZVOUS will generate a plot of the orbits of the space station and your shuttle craft. Each will proceed on the orbit plot until you presss any key to enter the command mode. Your objective is to rendezvous with the space station. From the command mode you can call for the orbital changes required to accomplish this objective, or you can call for the Options Menu.

Once you have elected to change the orbit, RENDEZVOUS will freeze your present orbital position and display another image of the spacecraft one orbital position in advance of your present position. This facilitates your planning for orbital maneuvers in advance. Always stop orbital cruise and set up your maneuvers at least one orbital position in advance of where you wish the maneuver to take place.

You can project an orbit foward (and subsequently backward again) by using the (←) and (→) arrow keys to pick the spot where you want the maneuver to take place. The station orbit is projected forward simultaneously so that you can judge the effect of the maneuver on the relative positions of the spacecraft and space station. Press the (RETURN) key when you have projected the orbit to the maneuver position you want. Press the escape key (ESC) to cancel these functions and return to orbital cruise.

After you press the (RETURN) key, answer yes (Y) to the "Calculate new orbit?" query in order to set up a trial maneuver at this position (any other key will send you back to the orbit projection routine). You are now given a choice to circularize the orbit or to set up a custom maneuver. If you select auto-circularization, RENDEZVOUS will calculate the burn direction and velocity. If you select a custom maneuver, RENDEZVOUS will ask you first to enter the thrust angle (this angle is the direction in which the impulse is to be applied, and is measured in degrees from your present direction of motion). Second, RENDEZVOUS will ask you for DELTA-V, the incremental velocity you wish to apply in the specified direction. (A non-numeric response to any of the above requests will cancel the trial maneuver). The figure below illustrates these parameters.



The parameters of your new trial orbit will be calculated and displayed. The energy (fuel) which would remain after the trial maneuver will also be displayed (DELTA-V). Notice that the available energy is always given in terms of the amount of velocity change which can be accomplished using it. If you indicate that these parameters are okay, then the new trial orbit will be plotted.

Do not worry if your trial orbit enters the atmosphere. You may select it knowing full well it will lead to disaster if unchecked, and then readjust it to complete rendezvous with the space station.

RENDEZVOUS will ask next if you want to project this trial orbit forward. If you do, the system works just as before moving the spacecraft and station forward (or backward) in their orbits, with the spacecraft moving on the new trial orbit. This feature will help you judge the impact of the maneuver on the relative positions of the spacecraft and space station. During this orbit projection routine, the computer will plot a cross at the point where the orbits intersect if the spacecraft and space station are in close enough proximity to achieve rendezvous. Press the escape key (ESC) to cancel the trial orbit projection routine and return to the trial orbit start.

If you select the new orbit, the maneuver data will be stored for later execution at the specified position in the orbit. You will then be returned to orbital cruise. If you do not select the trial orbit, the plot will be erased and you will be given the opportunity to plot a new trial orbit. If you do select the new orbit and later wish to cancel it, just hit any key during orbital cruise.

Use the above procedures to manipulate your orbit so that the spacecraft crosses the orbit of the space station at the same moment the space station arrives there. Once you have achieved an orbit with a rendezvous crossing, you must set up a maneuver to circularize your orbit at the rendezvous point (otherwise you would simply fly past the station). Set up this maneuver BEFORE reaching the rendezvous crossing.

HINT: This portion of the simulation is set up so that you can play with thrust angle and velocity to see the effect each has on orbital motion. Rendezvous is most readily accomplished, however, if you first set yourself up in a circular orbit well below or well above the station. Below the station, you will be moving faster than the station, and will outpace it. Above the station, you will be moving slower than the station, and it will outpace you. Be patient and wait until the distance between you and the space station has closed to within about 10 orbit plot points before starting trial maneuvers.

When in circular orbit below the station, always use a thrust angle of zero degrees and vary both DELTA-V and maneuver position to find a transfer orbit with a rendezvous crossing. The procedure is the same if you are above the station except that you should always use a thrust angle of 180 degrees. The maneuver position is most important, and should be varied after having found a

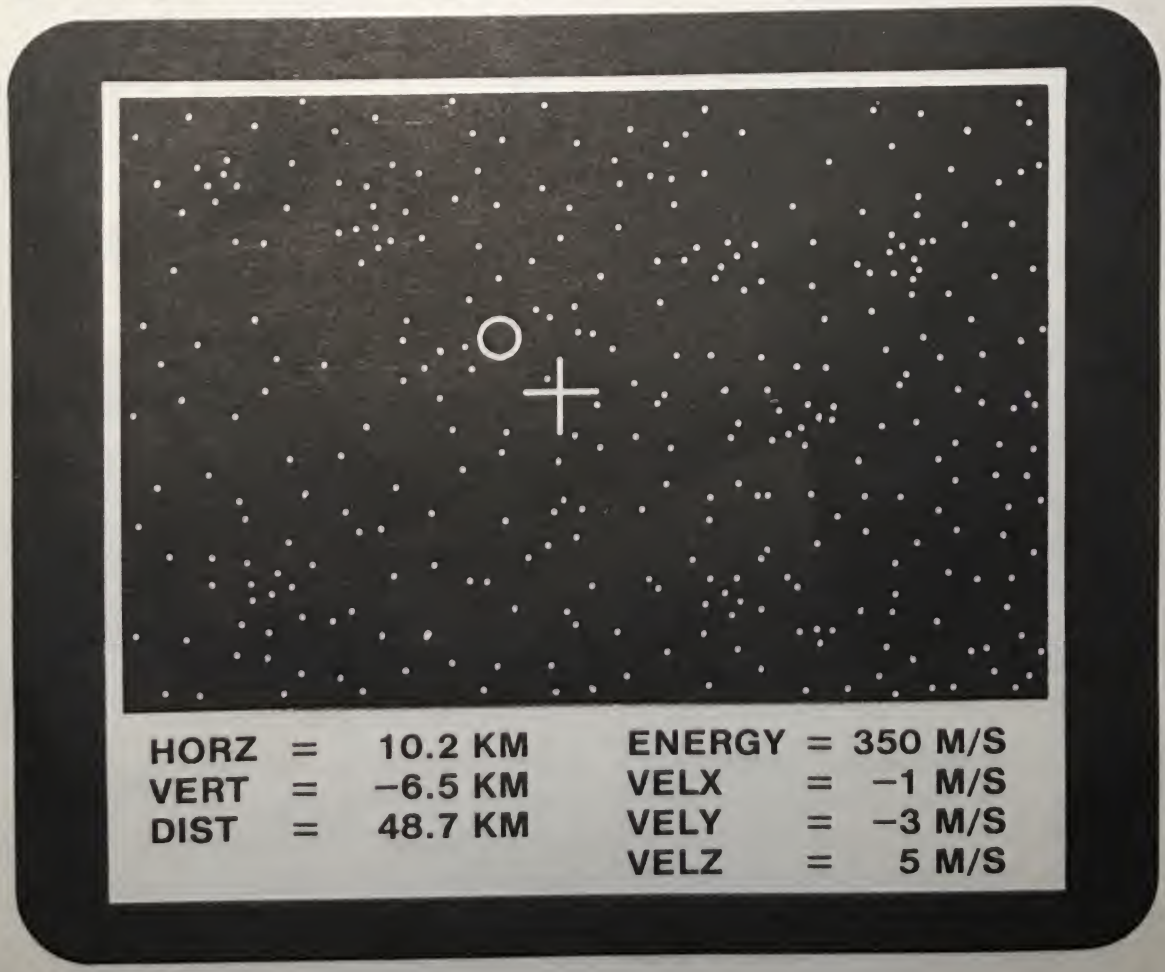
DELTA-V which results in a crossing orbit. If you allow the distance between shuttle and space station to close, then the opportunity will have been lost.

Phase Three: APPROACH

Techniques for orbital rendezvous and approach to an orbiting platform were perfected during the Gemini series of two-man spacecraft flights in the mid-1960's. The target in those days was an abandoned orbiting Agena rocket stage. A docking collar was attached to the Agena, enabling astronauts to practice docking with an external port. This same technique was used for the Apollo-Soyuz flight in the 1970's.

You have already emulated the orbital rendezvous accomplished in these missions in your Phase Two flight. Next you must approach the target. Radar and blinking navigational lights guided the approach by the Gemini and Apollo-Soyuz flights. Your RENDEZVOUS shuttle makes use of similar systems.

In Phase Three you start at a distance from the space station determined by the results of your orbital rendezvous. From this distance you must maneuver to within 2 km. of the station in order to begin the Docking Phase. In the approach phase you will be shown a wide angle view of the space ahead of the spacecraft. The blinking dot on the screen is the station. Radar data is shown below the screen giving the distance (DIST) from the station along the orbit; the approach velocity (VELZ); the horizontal (HORZ) and vertical (VERT)



displacements from the orbit path; and the horizontal (VELX) and vertical (VELY) velocities relative to the station's orbital path. The rotational motion of the spacecraft automatically stabilizes to point along the orbital path, so that you need only adjust your directional velocities. This is accomplished using a joystick or your keyboard as described in the **OPERATIONAL SUMMARY**. Directions and velocities indicated as positive are forward, up, and to the right relative to the space station.

To successfully enter the Docking Phase, you must maneuver to within 2 km. of the station and reduce your velocity in each direction to 20 meters/second or less. The approach control engines used in Phase Three burn with 5 m/s increments. You can trim any residual velocities in the Docking phase using the attitude control thrusters.

If you happen to pass the station in its orbit, your on-board gyros will automatically turn the spacecraft 180 degrees to face the station again. Collision with the station is possible, so be on the alert. Each pass of the station costs you proficiency points.

Phase Four: ALIGNMENT AND DOCKING

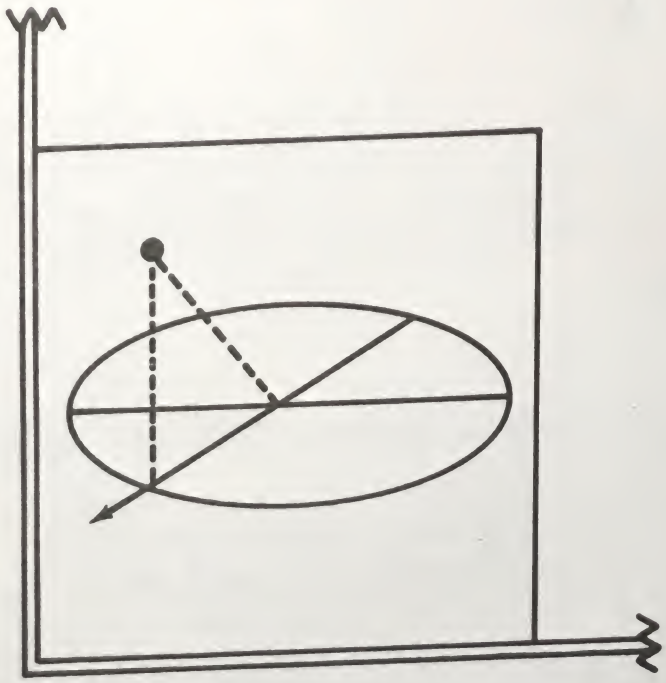
At this writing the NASA space shuttle has yet to rendezvous and dock with an orbiting vehicle. Space stations which the actual shuttle might visit exist only on drawing boards in NASA dream factories. In RENDEZVOUS' Docking phase you are a pioneer, doing it for the first time, piloting a realistic simulation to show NASA how its objectives might some day be accomplished. This is the way it might be done in the future.

Now that you are in the vicinity of the space station, you final objective is to enter the docking port. The narrow angle screen has been activated, and you are given control of the rotational motion of the spacecraft. Use toggle switch #3 on the joystick, or use your keyboard to control rotation. You must approach the space station and maneuver the spacecraft to a position immediately in front of the aperture in order to enter the docking port. The space station is 220 meters in diameter. Avoid collision!

When you first enter Phase Four, you are not given any radar rate data. You are only provided with the distance from the center of the station and the amount of energy remaining. The (H) key will toggle the radar on and off. You lose proficiency points for toggling the radar on, and continue to lose points while the radar is on. The on-board radar gives you rate information. Rates in degrees/second are given for rotation about each spacecraft axis; ROTH for heading left or right, ROTP for pitch up or down, and ROTB for bank left or right. Rates in meters/seconds are given for directional motion along each spacecraft axis; VELX for left or right, VELY for up or down, and VELZ for forward or back. The positive directions are forward, up and right.

Instead of simple port-hole parking (as NASA's shuttle is likely to use), this huge space station sports a hangar-sized docking port into which you can fly. The closed door of the docking port appears as a rectangular structure in the smaller axial face of the space station. A vertical strut above the door indicates the top of the port for correct rotational alignment.

If you lose sight of the station at any time, and are uncertain where it is, you may toggle the direction finder using the (G) key. A figure will appear at the lower left of the screen to show you where the station is located relative to your spacecraft.

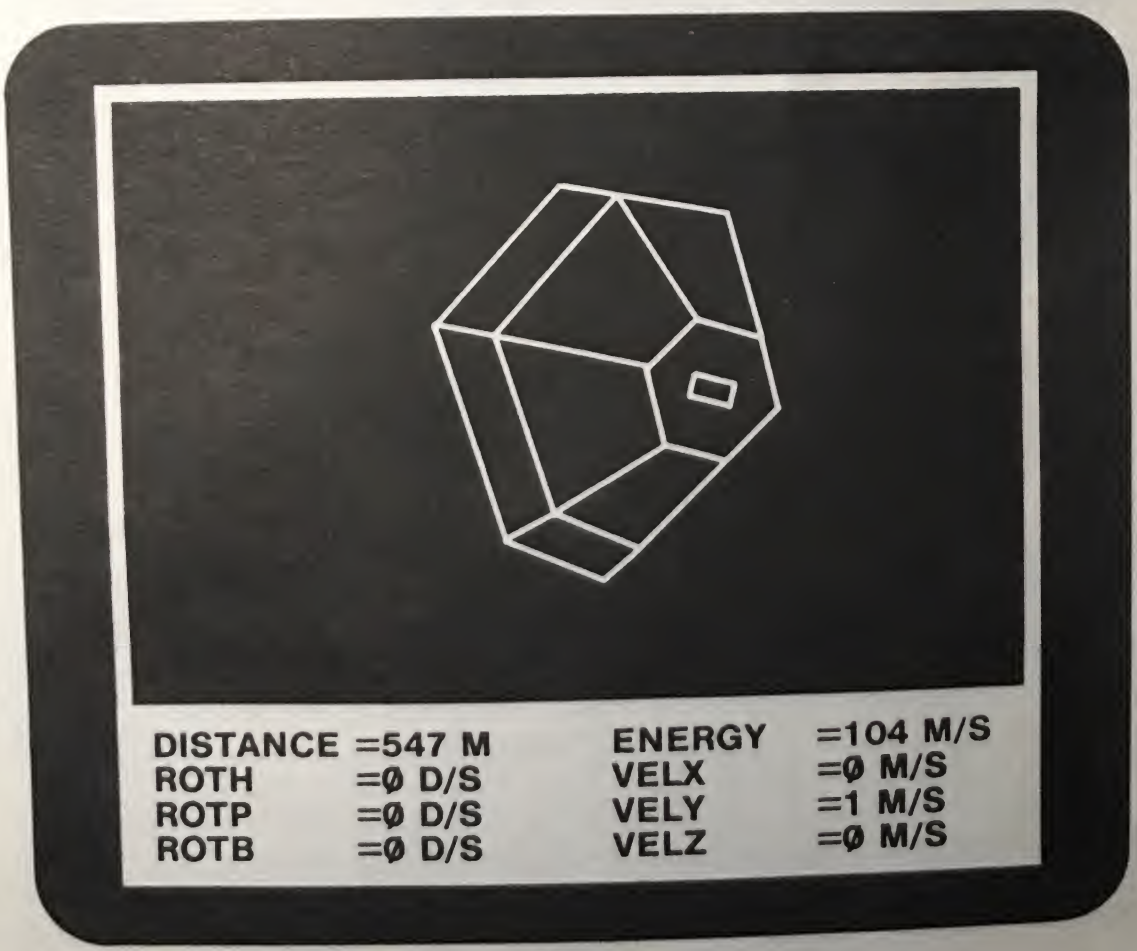


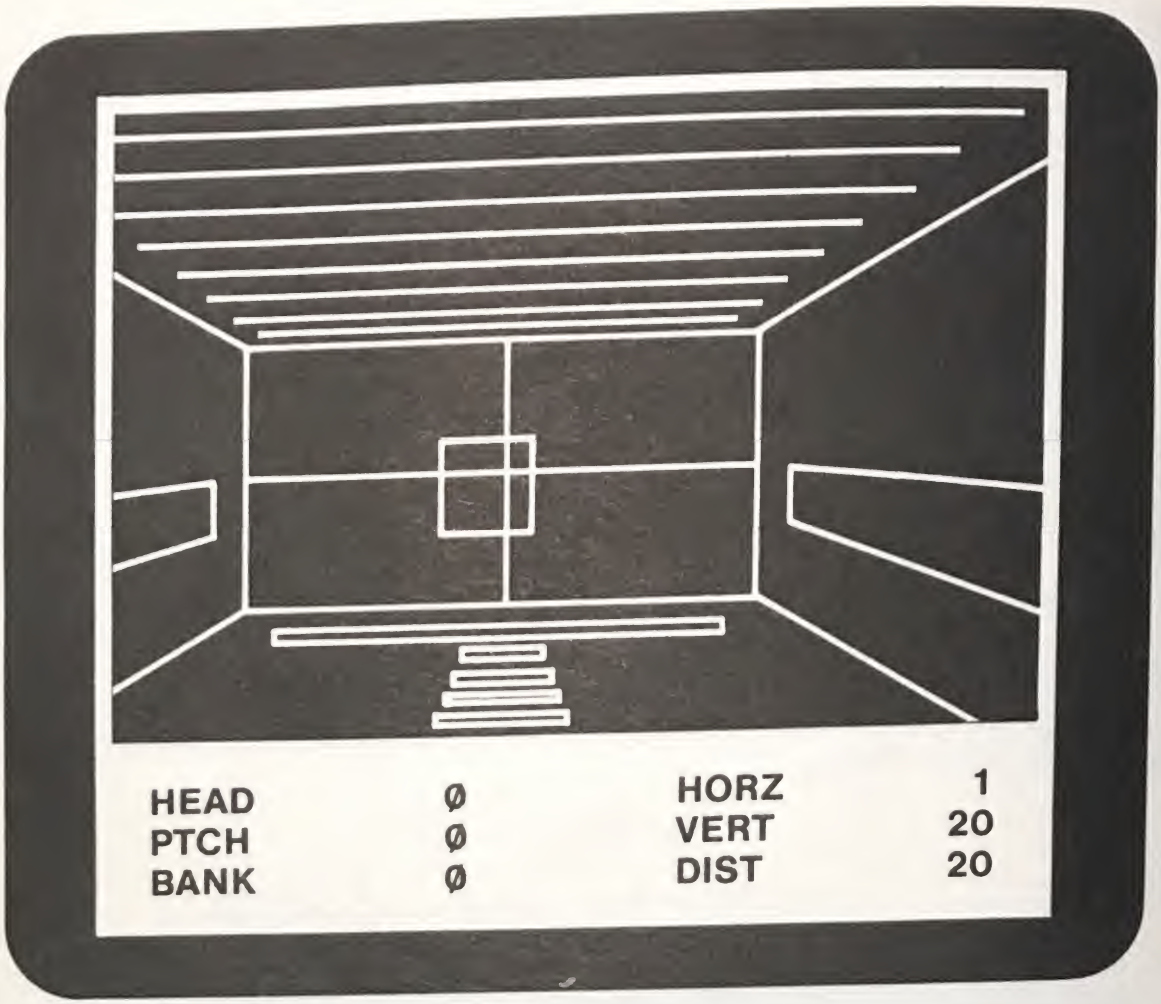
The circle is the "floor" of the spacecraft. Imagine you are standing at the center of the circle and facing outward in the direction of the arrow. The arrow points forward, in the +Z direction. The other axis in the circle is the horizontal, or X axis. The example on this page shows the station above and to the right of the forward window, so that the spacecraft must be rotated (headed) right and rotated (pitched) up in order to face the station. You lose proficiency points any time you toggle the viewfinder on, and continue to lose points as long as it remains on.

The moment you maneuver into the vicinity of the docking port you will suddenly find yourself facing the "docking corridor." This corridor is an imaginary cylindrical space 32 meters in diameter and 42 meters long directly in front of the docking port. Once inside this corridor, the docking port doors are opened. There are cross bars at the far inside end of the port to help with alignment. Your monitor will provide radar data from the station radar link (provided without penalty). The station radar provides position data, as opposed to the rate data supplied by the on-board radar. Docking becomes extremely difficult without this data (try masking it off sometime!).

Rotational position is given as heading from the line of the docking port (HEAD), pitch above or below the approach line (PTCH), and bank angle relative to the port (BANK). Distance off the line of approach is given in the horizontal (HORZ) and vertical (VERT). The distance from the nose of your craft to the docking collar at the far end of the port is given as DIST.

During your approach to the station, you may have acquired some residual velocities along any of the three directional axes as a result of velocity increments applied in arbitrary rotational positions. These cannot be removed by the fixed velocity increments used in manual flying without a lot of rotational acrobatics, and the small motions can cause difficulty in the final docking procedure, where a good deal of thrusting is required to offset them. The RENDEZVOUS flight system can remove them. Pressing the (RETURN) key will command the system to remove incremental velocities along the directional axes, but it will cost you proficiency points. This command works only within the docking corridor, since the system requires station radar data to kill residual velocities relative to the station. You can also stop all rotational motion at once by pressing the (SPACE) bar at any time (but this will also cost you proficiency points).





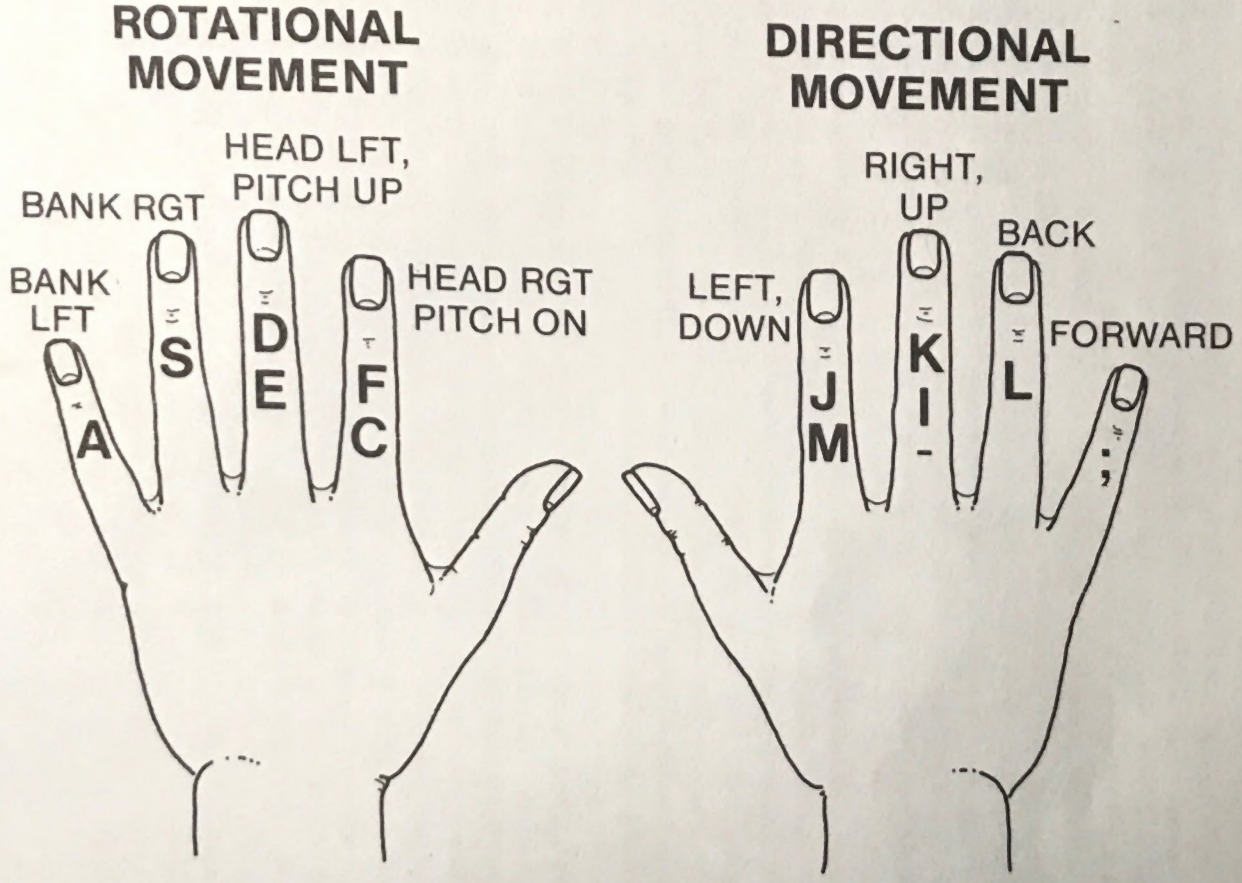
After you enter the docking port, continue until the spacecraft is entirely within the dock hangar (DIST=0). Inside the port, the spacecraft must be kept rigidly in control. Heading, pitch, and bank must not exceed 2 degrees. The horizontal and vertical distances off the approach line should not exceed 2 meters. Otherwise your craft will crash through the docking port walls.

IV. MANEUVERING

USING THE KEYBOARD

NASA pilots use joysticks to manually fire the shuttle's maneuvering system, and computer control for automatic maneuvers. You can manually fly your RENDEZVOUS shuttle with the computer keyboard just as effectively as with joysticks. Keyboard maneuvering will seem quite natural once you've jumped in and tried it. Your right hand is used to control directional motions and your left hand is used to control rotational motions. Your middle and index fingers have to do double duty, but if you are used to the Autostart ROM J, K, I, M editing keys it will come naturally. Just as the (J), (K), (I), (M) keys are used to move the cursor left, right, up and down when editing on the Apple II+, so they are also used to move the spacecraft left, right, up and

down. Each key press adds an incremental 1 m/s pulse in the appropriate direction (5 m/s in the far approach phase). Likewise, the rotational motion of the spacecraft is controlled by the (D), (F), (E), (C) keys using the middle and index fingers of the left hand. The pinky and ring fingers control forward and backward motion on the right hand ((;) and (L) keys), and bank rotation on the left hand ((A) and (S) keys).



You can determine placement of your hands on the keyboard by consulting the figure above and the one on page 8. Your middle and index fingers should rest on the (D), (F) and (J), (K) keys. You will find it easier to maneuver if your hands remain on the keyboard a la touch typing. It is difficult to respond quickly by hunting and pecking. The additional keys used — (ESC), (RETURN), (SPACE) bar, (G), (H) — can be reached with the fingers as listed in the figure above, while your hands remain on the keys.

The bail-out key, (ESC) allows you to stop momentarily in order to assess your status and/or return to the Options Menu (see section II). The (G), (H), (RETURN) and (SPACE BAR) keys are explained in sections II and III.

USING A JOYSTICK

The joystick provides a more realistic control mechanism to fly the spacecraft than the keyboard, although only one stick is available. Therefore, the single joystick must be alternately used for translational motion and rotational motion. If you have a 3-button joystick, you can use switch #3 to toggle the joystick between these two controls. If you have a 2-button joystick, or if you are using paddles, the backslash (/) key on your keyboard will toggle between transitional and rotational motion. The RENDEZVOUS instrument panel will show a column of "<" or ">" characters, pointing to the three motions presently affected by the joystick. Switches #1 and #2 act as throttles to control forward and backward motion. The figure on page 8 shows how the joystick controls affect spacecraft motion. Five keyboard keys remain operative in the joystick operating mode; the (G), (H), (ESC), (RETURN) and (SPACE) bar keys (as described above).

GLOSSARY OF TERMS

ACCELERATION: increasing or changing velocity.
ALTITUDE: height above the surface.
ATTITUDE: rotational position.
AXIAL: along the main rotation axis, or the axis running forward and backward as perceived from within a rotating body.
AXIS: a line through a body about which it rotates.
BALLISTIC: motion under the influence of gravity but without atmospheric lift or drag.
BANK: rotation around the axial direction either left or right.
BOOSTER: first stage of a multi-stage rocket, usually with high power but short burn duration.
CENTRIFUGAL FORCE: force acting to move a rotating body away from the center of motion.
DELTA-V: velocity change (acceleration).
ELLIPTICAL: non-circular, elongated.
FORCE: work or energy applied to move an object (acceleration applied to mass).
GYROS: gyroscopes, which establish a reference for rotational motion.
HEADING: Yaw or rotation about the vertical axis left or right.
HORIZONTAL: the axis running exactly left and right as perceived from within a rotating body.
IMPULSE: force applied over a short time.
INCREMENT: small change.
INERTIA: the tendency to remain in constant motion in the absence of any applied force.
KILOMETER: 1000 meters, or 0.621 of a mile.
METER: 39.37 inches.
ORBIT: unpowered motion around a central object or force field.
PARAMETER: a number or variable which characterizes what is being described: i.e. velocity is a parameter describing motion.
PITCH: rotation about the horizontal axis up or down.
PROJECTION: to look ahead in time or space.
RADIUS: distance from the center, size of circle as measured from the center (½ diameter).
RENDEZVOUS: to meet and move together.
RESIDUAL VELOCITY: small remaining velocity usually difficult to remove.
ROTATIONAL MOTION: tumbling motion of an object about some center within it.
SUSTAINER: main engine or rocket stage, usually the longest burning.
TRAJECTORY: flight path.
THRUST: force producing motion.
THRUST ANGLE: the direction in which the impulse is to be applied.
TRANSLATIONAL MOTION: motion in a straight line.
VECTOR: an indicator of direction and magnitude, an arrow drawn in the direction of motion with a length proportional to the magnitude.
VELOCITY: speed vector.
VERTICAL: the axis running up and down as perceived from within a rotating body.

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